UNIT 2 - FUELS
SECTION 2 - FUELS FOR EVERYTHING

Vocabulary

alcohol
aliphatic
ambient
benzene
biochemical conversion
conversion
biofuel
biogas
biomass
British Thermal Unit
butane
carbon dioxide
carbon monoxide
catalytic conversion
clean diesel
coal
diesel
fission
formaldehyde
fuel oil
fusion
furnace
gasoline
incinerator
jet fuel
kerosene
landfill
methyl tertiary butyl ether
municipal solid waste
nuclear energy
nuclear reaction
oxygenate
oxygenated gasoline
reformulated gasoline
refuse
syngas
thermochemical
transesterification
vapor lock
volatility
waste to energy plant

When you're out camping, you use the sun's radiant energy to see what you're doing. But what happens when you need light after the sun goes down? You produce light by using fuels you have brought along: You make a wood fire, light a kerosene lamp, or start an electrical generator fueled by gasoline. (You might also use a battery-powered flashlight, but remember that a fuel was probably used to generate the electricity that charged the batteries.)

Figure 2-2-1 *When you're out camping, you produce light by using fuels you have brought along.*

A fuel is normally a chemical energy source whose energy is released for use by combustion (burning). Uranium and plutonium are the exceptions. Because uranium and plutonium also must undergo a human-controlled reaction to release nuclear energy, they are often called nuclear "fuels" even though they are not burned.

The most common primary energy sources we use today are fuels: petroleum products, natural gas products, biomass, coal. Fuels are popular as energy sources because, as chemical energy, they are in a potential state. This means they can be stored for use when needed, unlike energy in a kinetic state.

This ability to transport and store fuels rather easily has spurred people to find ingenious ways to use them. Fuels are often used for moving vehicles and for heating or cooling. Fuels are also used as a primary energy source to produce electricity, a secondary energy source.

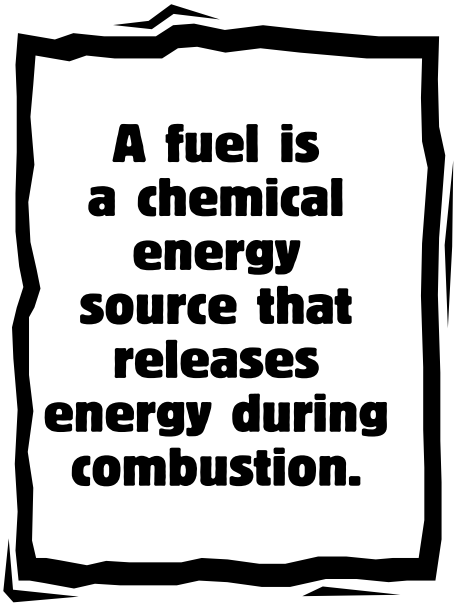

Figure 2-2-2 A fuel is a chemical energy source.

Advantages such as long-term storage and convenient transportation make fuels seem like the perfect energy sources for humankind. However, most fuels are not easily renewable. So, although kinetic energy sources are difficult to control over the short run (a cloudy day may block the sunlight you need), they are reliable in the long run (the sun comes up every day).

Non-transportation Fuels

The first group of fuels we will discuss are those not currently used for transportation purposes, though such an application is not impossible. These are **biogas**, **biomass**, **butane**, **coal**, and **syngas**.

Biogas

Whenever organic matter decays, methane, carbon dioxide, and other gases are produced. Instead of allowing landfill gas to escape into the air, the gas can be captured, converted, and used as an energy source. Landfill gas can be converted and used to generate electricity or as an alternative vehicle fuel.

One person's waste...

Biofuels result from conversion of biomass, the recent remains of organisms or their wastes. Although fossil fuels come from ancient organic remains, they cannot be quickly replaced as biofuels are.

Biofuels are renewable. They are produced in three ways: **biochemical conversion**, which uses organisms such as bacteria; **transesterification**, which uses **alcohols**; and **thermochemical conversion**, which uses heat. Examples of biochemically converted fuels covered in this chapter are biogas and ethanol. Transesterification of vegetable oils yields biodiesel. Thermochemically derived fuels include biomass-based syngas and wood-distilled methanol.

Biofuels are not generally cost competitive, but could become so with advances in technology and increases in the cost of oil. One successful example of biofuels is New York's Fresh Kills landfill, which sold its first biogas in 1982. About 180 wells, drilled to an average depth of 60 feet, are connected by seven miles of plastic pipe to the inlet of a methane recovery plant. The gas is purified to pipeline quality and transferred to a gas utility that odorizes and measures it. The facility cost a total of $20 million. In less than three years of operation, the plant sold more than 3 trillion **British thermal units (Btu)** of gas, generating about $15 million.

Biofuels could potentially replace one-third of U.S. consumption of fossil fuels. However, some people wonder whether energy crops, such as sugar cane for ethanol production, should be cultivated in preference to food crops. Biofuels produced by waste products, such as garbage or sewage sludge, are not subject to this objection.

Three cities in Texas that "mine" landfill gas are Austin, Houston, and Lewisville. The first facility in Texas to use landfill gas to generate electricity was in Lewisville. The Lewisville facility generates enough electricity to provide power to 6,500 homes. The facility in Houston generates the most electricity, providing 11,000 homes with power. Austin generates enough electricity to power almost 2,000 homes.

Of the 6,000 landfills in the United States, only 270 operate landfill gas-to-energy projects. The U.S. Environmental Protection Agency estimates that as many as 700 additional landfills could cost-effectively convert biogas into enough electricity to power 3 million homes and reduce pollution by an amount equivalent to removing 24 million cars from our highways.

Biomass

Biomass energy, considered an alternative energy source in the United States, comes from burning wood and wood waste, crop waste (such as straw), trash, or similar organic materials. In the United States, these generally go toward producing electric power. You can see why such fuels would be difficult to use for vehicles—though instances of wood-burning cars have been documented in petroleum-starved countries.

Waste to Energy

Municipal solid waste (MSW) is composed of residential and commercial **refuse** and makes up the largest source of waste in industrialized countries. MSW can be converted into heat or electricity by various methods. These methods produce usable energy from organic material that would otherwise be wasted.

Waste-to-energy plants can produce a number of pollutants. These include carbon monoxide, sulfur dioxide, and fine particles containing heavy metal compounds. However, unlike traditional waste **incinerators**, waste-to-energy plants are strictly regulated. The generation of pollutants and their release into the atmosphere are greatly reduced by federally required air-pollution control devices.

The three main methods of conversion are:

1. **Mass burn**—Refuse is burned just as it is delivered to the plant, without processing or separating. Mass burn facilities can incinerate up to 3,000 tons of refuse per day. The fire heats boilers, making steam for electricity.
2. **Burning in modular combustion units**—These are, for the most part, simply small mass-burn plants with capacity ranging from 25 to 300 tons per day.
3. **Refuse-derived fuel**—Waste is processed in the plant to remove non-combustible items and recyclables and to shred the combustible waste into smaller, uniform particles.

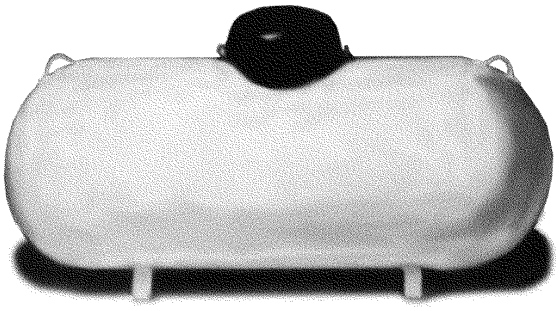

Figure 2-2-3 *Butane tanks look just like propane tanks, but the fuels are quite different. Butane has a higher boiling point, 32˚F, making it less usable in cold weather. Propane, which remains a gas down to -44°F, has replaced butane in most cold-weather areas.*

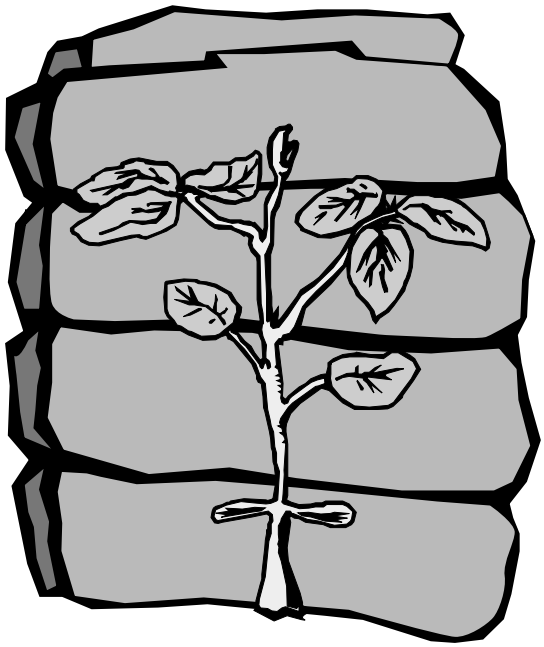

Figure 2-2-4 *Coal is a fossil fuel formed from the remains of plants that were buried beneath the earth millions of years ago.*

In Texas, biomass comes either from agriculture and forestry waste or city solid waste. A sugar mill in the Rio Grande Valley burns sugar cane waste fiber to produce steam to generate electricity. About half of the lumber companies and 75 percent of the paper companies in Texas use wood waste to generate electricity. And cities such as Center, Cleburne, Carthage, Gatesville, Palestine, and Waxahachie burn solid waste to recover energy.

Butane

Butane is a gaseous hydrocarbon derived from petroleum or natural gas that liquifies under slight pressure. It is used in small bottles for torches, small cookstoves, and even curling irons. It has lost popularity as a home heating fuel in colder climates because it will not vaporize for use if the **ambient** temperature falls below 0°C (32°F). Butane is still very popular for heating and cooking in Latin America and other relatively warm climates. Butane can be used to power automobiles, but is not used now because of its relatively high boiling point.

Coal

Coal accounts for 23 percent of the world's fuel consumption. About 86 percent of all coal produced in the United States is burned in boilers to produce steam, which drives turbines that produce electricity. About 56 percent of the United States' and 40 percent of the world's electricity is produced from coal. In this country, most of the rest of the coal is used as an industrial fuel, but it was not that long ago that it was burned in most homes for heat. And don't forget that the steam locomotive was powered by a coal-burning furnace!

Lignite, or brown coal, is the only type of coal mined in Texas. Bituminous coal is the most common type, and hard anthracite is in limited supply and expensive. In some countries, peat—densely matted vegetation that is the precursor to coal—is dried and burned.

Alternative uses may be found for gasified coal. Processes are under development that will convert solid coal into gaseous or liquid fuels.

Syngas

Syngas is a mixture of hydrogen and **carbon monoxide**. Its name is an abbreviated form of "synthesis gas." It can be derived from biomass using a process involving heat, steam, and oxygen, or it can be created from coal. Syngas can be used like natural gas, as a source of hydrogen for fuel cells, or reformed into other hydrocarbon fuels. It is considered an alternative to conventional fuels in all its applications.

Synthetic gasoline, diesel, methanol, and other transportation fuels can be produced from syngas. One **catalytic conversion** process was first developed in Germany in the 1920s and produces a wide range of hydrocarbons, alcohols, and other substances. Most of the hydrocarbons are components of gasoline and diesel. The other way to derive gasoline and diesel from syngas is to first convert the gas to methanol, and then into the conventional fuels.

Conventional Transportation Fuels

Conventional transportation fuels are **diesel**, **fuel oil, gasoline**, **kerosene**, **oxygenated gasoline**, and **reformulated gasoline**.

Diesel

Diesel is a complex mixture of hydrocarbons distilled from petroleum. It is composed mainly of compounds that will auto-ignite from the heat of compression in a diesel engine—no spark plugs are necessary. Diesel fuel is used mainly by heavy-duty and medium-duty trucks, construction equipment, locomotives, and marine and stationary engines.

Figure 2-2-5 *Medium-duty diesel delivery truck*

Though diesel engines are efficient and powerful, diesel exhaust is dirty. You can see this in its black color and strong smell from tiny soot particles and sulfur compounds.

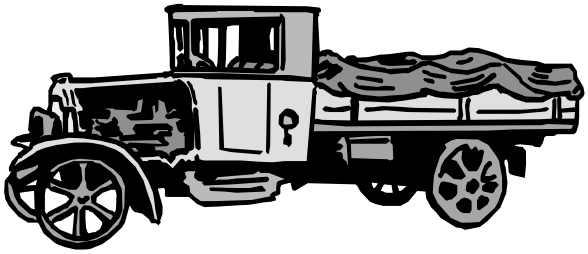

Figure 2-2-6 *Benz Diesel Truck, 1923*

In some places, including Texas, diesel can be considered an alternative transportation fuel if it is burned in engines that can meet certain emission standards. Since 1994, oil companies have created "**clean diesel**" formulations, which are lower in sulfur than traditional diesel. No manufacturer yet sells a diesel engine that can meet the most stringent emission standards.

Fuel Oil

Fuel oil is a heavy petroleum product. It is used for residential and commercial heating, manufacturing processes, and industrial steam and electrical generation. It is also used in ships driven by steam turbines.

Gasoline

The fuel most associated with the motor car is, of course, gasoline. Gasoline is a complex mixture of volatile hydrocarbons distilled from petroleum. **Volatility** indicates a fuel's ability to vaporize. Gasolines must be more volatile in cold weather to ignite properly and allow the engine to run smoothly as it warms up. In warm weather, volatility must decrease to prevent excess vapor from forming.

Regular, oxygenated, and reformulated gasolines have most of the same component hydrocarbons, but differ in the relative amounts of the various hydrocarbons and **oxygenates** they contain. The intent of using oxygenated and reformulated gasoline is to keep performance as close as possible to that of conventional gasoline, while reducing emissions.

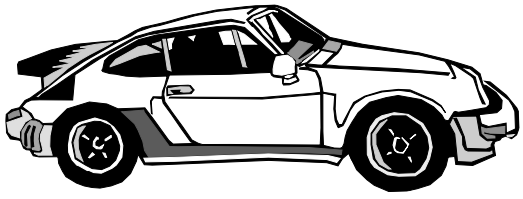

Figure 2-2-7
Modern gasoline contains a sophisticated blend of additives such as de-icing agents, anti-knock substances, and detergents. Oil companies cooperate with engine manufacturers to develop fuels tailored to modern engine design.

For years, lead was added to gasoline to prevent engine "knock." But leaded gasoline is no longer sold in the United States because of concerns about lead's health hazards.

Performance criteria include driving range, miles per gallon, cold-start ability, smooth running after warm-up, and avoidance of **vapor lock**. Fuels should also prevent spark plug fouling, filter plugging, and excessive engine wear. Today, gasoline's hydrocarbon mix must also stay within federal standards for evaporative and exhaust emissions.

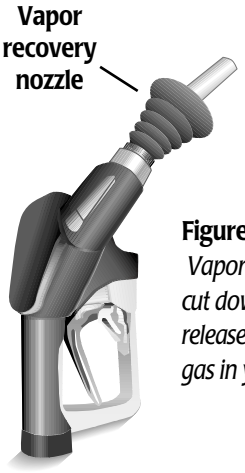

Figure 2-2-8
Vapor recovery nozzles cut down on vapor release when you put gas in your car.

Energy content is important when comparing gasoline with other fuels. The weight of each fuel and the volume required to produce a mile of travel (which is a function of energy content) are important differences among fuels. One liter (1.76 pints) of gasoline will release about 40 million joules when burned completely. Depending on how it is burned, most of this will become heat immediately. This makes gasoline a very convenient fuel to burn in engines.

Kerosene

Figure 2-2-9
Kerosene lamp

Kerosene is derived from petroleum and is similar to fuel oil, though less ignitable. It has long been used for lanterns, small space heaters, and as a solvent and thinner. In many developing countries, kerosene is widely used for lighting and heating as an alternative to scarce natural resources such as firewood.

Jet fuel is highly refined kerosene. Because aircraft fly more than 900 billion miles around the world every year, kerosene fuels represent a sizeable market.

Oxygenated Gasoline

Oxygenated gasoline is gasoline that contains 2.7 percent oxygen by weight. It is mandated by law to address excessive carbon monoxide (CO) during the winter in many U.S. cities, including El Paso. Consumers in these areas use about 30 percent of the nation's gasoline.

Carbon monoxide emissions result from incomplete combustion and are worse when temperatures are low. High altitude also increases CO emissions in vehicle exhaust, particularly during cold starts. Increasing the oxygen content of gasoline improves combustion and reduces CO emissions. Oxygenated gasoline can be burned in today's gasoline engines without equipment modification.

Gasoline's oxygen content comes from oxygenates, liquid organic compounds, such as alcohols or ethers, that contain oxygen. Oxygenates such as ethanol and **methyl tertiary butyl ether (MTBE)** displace petroleum and reduce CO emissions.

Wintertime oxygenated fuel programs appear to have been successful in reducing CO in affected areas.

Reformulated Gasoline (RFG)

Reformulated gasoline (RFG) is a type of gasoline that has had its chemical composition altered and an oxygenate such as ether or ethanol added to reduce volatile toxic components and increase the oxygen content. RFG reduces the emissions of toxic substances such as benzene and formaldehyde. It also has less tendency to form ozone. RFG can be burned in gasoline engines without modification.

Switching over to reformulated gasoline (RFG) was mandated by the federal Clean Air Act amendments of 1990. The U.S. Environmental Protection Agency has been working with states to implement a two-phase reformulated gas program to improve air quality.

Phase I, which began in 1995, required RFG to contain a minimum of 2 percent oxygen by weight, maximum of 1 percent benzene by volume, no heavy metals, and detergents to prevent accumulation of deposits in engines and vehicle fuel supply systems. RFG was also required to reduce volatile organic compounds (VOC) and toxic air emissions. Phase I reduced smog-forming pollutant levels by about 17 percent compared to conventional gasoline.

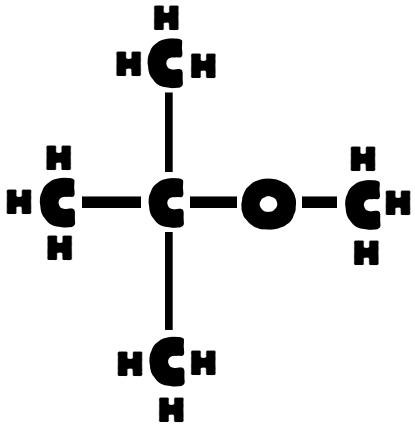

Figure 2-2-10 *Structural formula of methyl tertiary butyl ether (MTBE).*

Phase II, which began in 2000, required RFG to further reduce hydrocarbon and toxic emissions. Phase II is expected to reduce smog-forming pollutants 27 percent more than conventional gasoline.

The 1990 amendments also mandated the sale of RFG in U.S. cities with the highest levels of ground-level ozone pollution. Currently, RFG must be sold in 10 affected areas, and other areas have voluntarily opted to use RFG. In Texas, RFG is sold in the Houston and Dallas-Fort Worth areas.

As with clean diesel, the state of Texas classifies RFG as an alternative fuel if it can be shown to meet low-emission vehicle standards. Some other states do not recognize RFG as different enough from conventional gasoline to qualify as an alternative fuel.

Nuclear

Nuclear energy is released when atomic nuclei split or combine (fuse). The kind of nuclear energy used by people today comes from the power released by the fission of uranium atoms.

Nuclear **fission** is the splitting of an atom into two or more parts (figure 2-2-11). When that occurs, a large amount of energy is released in the form of higher energy neutrons. The release can occur very quickly, as in an atomic bomb, or in a more controlled manner, within a **nuclear reactor**, that allows the energy to be transformed for conventional uses.

Nuclear power plants initiate and control fission, then use the thermal energy to make steam, which drives turbines. Many countries use this application of nuclear power to generate a significant share of their electricity, and it is now generally considered a conventional energy source.

Nuclear power results in almost none of the greenhouse and acid-forming gaseous emissions associated with fossil-fuel power plants. The normal operation of a nuclear power plant does release small amounts of radiation into the environment and creates radioactive material that must be transported and stored. These materials can remain highly radioactive for thousands of years.

Fission also has a specialized use as an alternative transportation fuel. Small nuclear reactors drive the engines of some submarines and large ships, such as aircraft carriers. This is a very expensive way to travel, but the small volume of fuel needed allows these vessels to cruise for months without putting in to port.

Fusion is the other form of nuclear energy. In fusion, smaller nuclei combine to make larger nuclei. As with fission, large amounts of heat, light and other wavelengths of radiation are released when this happens. The sun combines hydrogen atoms into helium atoms by a fusion process, releasing vast amounts of energy.

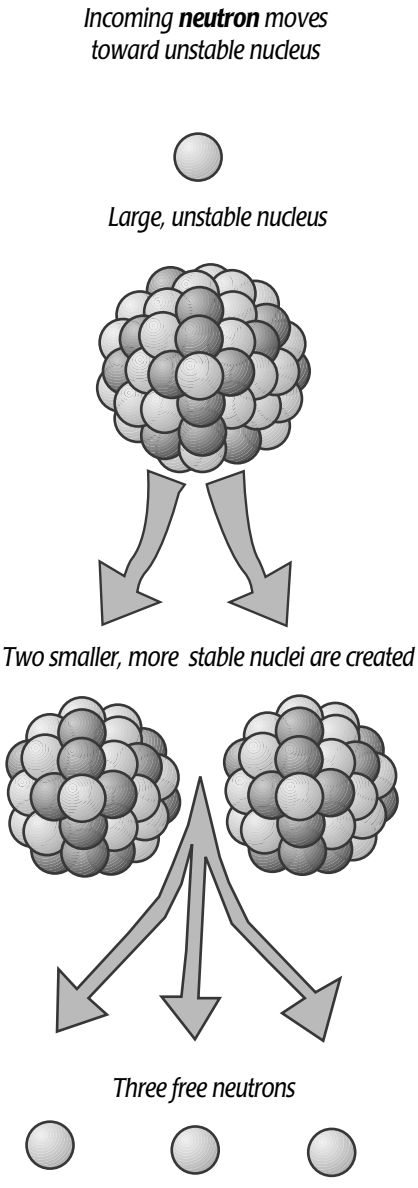

Figure 2-2-11 Nuclear fission

Fusion of nuclei occurs on earth when atomic particles are accelerated to high speeds in a vacuum and made to strike either a fixed metal target or a beam of particles traveling in the opposite direction. Fusion is also the process used in thermonuclear (hydrogen) weapons.

Today the International Thermonuclear Experimental Reactor (ITER), a large fusion device, is being developed by Russia, the United States, Europe and Japan. The ITER is scheduled to become operational early this century. It is anticipated that the ITER will be the first fusion device to release more energy than it consumes.

Fuels for Everything Resource List

www.epa.gov
U.S. Environmental Protection Agency
EPA administers federal laws on air pollution and clean fuels. The agency's site has information about emissions, emissions research, and programs that promote clean air, such as the Reformulated Gasoline Program and the Landfill Gas-to-Energy Project.

www.acf-coal.org/index.html
American Coal Foundation, Washington, D.C.
Activities, videos, and general information about coal formation, coal mining, land reclamation and uses for coal.

www.stpnoc.com/
South Texas Project Nuclear Operating Company
"Explore Nuclear" on the site's navigation bar explains the workings of the nuclear electric generating plant located near Bay City, Texas.

www.gasification.org/story/explaine/explaine.html
Gasification Technologies Council
Diagrams the gasification process of converting any carbon-containing material into synthesis gas.

www.scienceteacherprogram.org/1999lp/nociti99.html
Columbia University
How Can We Calculate the Molecular Weight of Butane? A hands-on experiment using a butane lighter, a one-liter flask, a trough of water and and electronic balance.